SDO Mission Definition Team Kickoff Meeting

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Team Members

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- Tom Bogdan - High Altitude Observatory/NCAR
- Russell Howard - Naval Research Laboratory
- Steve Kahler - Air Force Research Laboratory

SDO MDT Charge

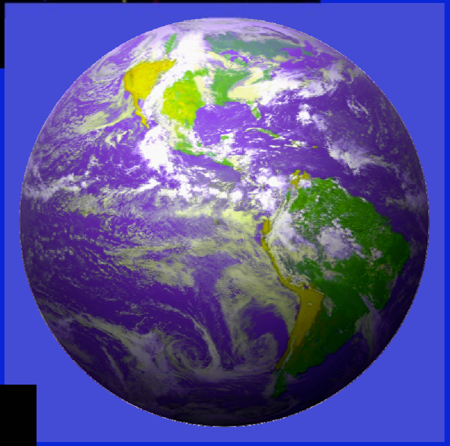
- To produce a Mission Definition Document that includes Science Requirements in sufficient detail to define a model mission for costing purposes by 15 May 2000.
- To communicate with the science community the goals LWS and SDO
- To receive comments and ideas from the science and user community that improve LWS and SDO
- To produce a brochure for the SDO Mission to explain SDO to a wide community

What do we need to accomplish today?

- Understand the SDO Baseline Approach
- Understand the charge to the SDO Mission Definition Team
- Understand the goals of LWS project
- Begin to understand the operational user's desires for Space Weather and Global Change Data

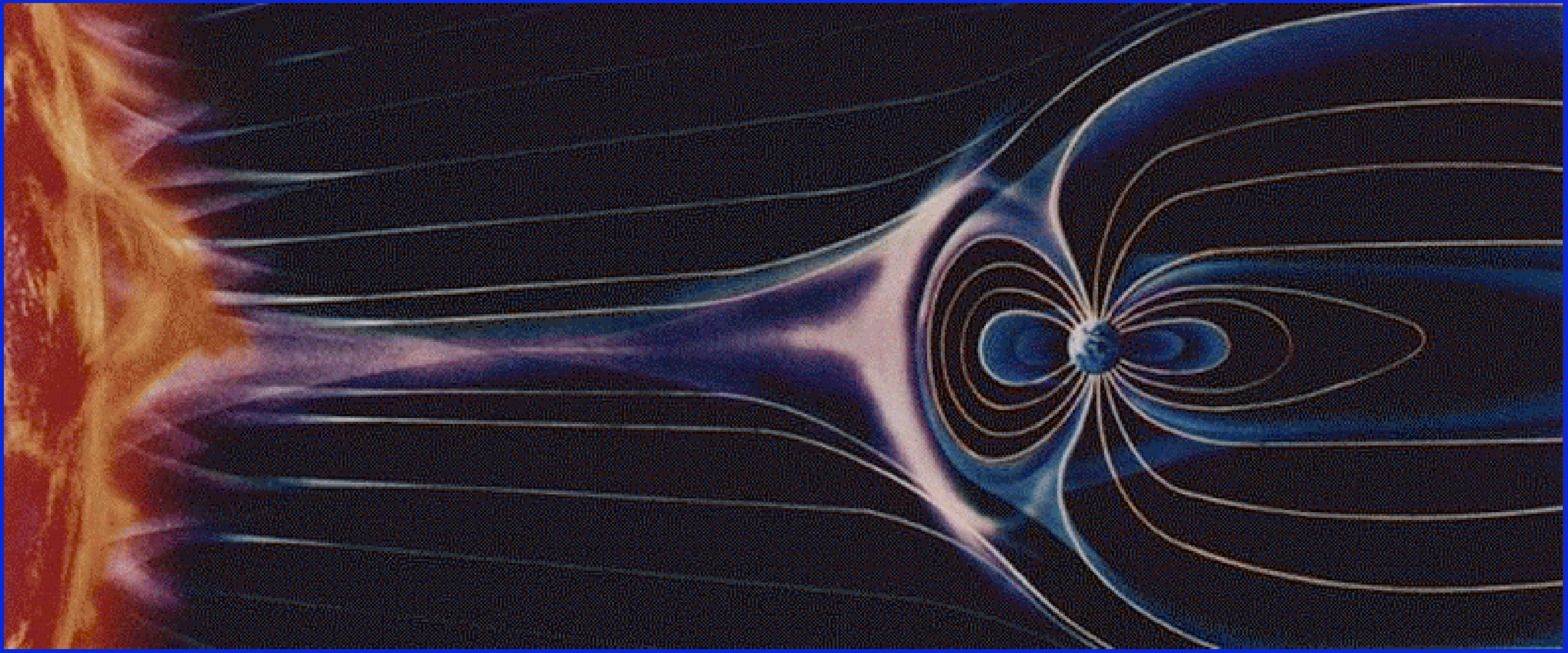
The Impact of the Sun on Society

- Solar Variability Affects Human Technology, Humans in Space, and Terrestrial Climate.
- The Sphere of the Human Environment Continues to Expand Above and Beyond Our Planet.
  - Increasing dependence on space-based systems
  - Permanent presence of humans in Earth orbit and beyond



Space Weather Definition

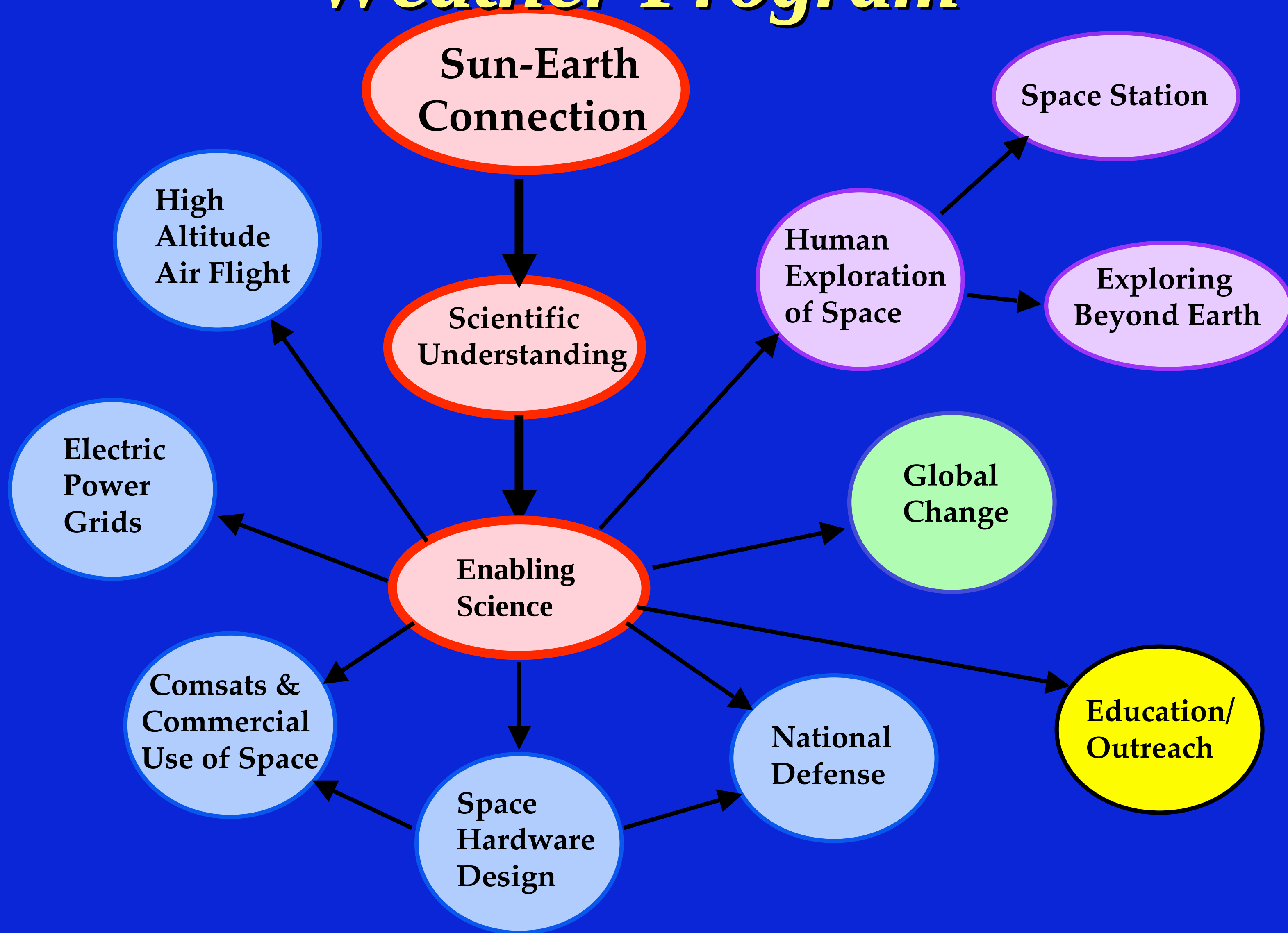
Conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems as well as endanger human life and health - Space Weather TOR 1998



LWS Provides the Basic Research Component of the National Space Weather Program

- *The Purpose of the Living With a Star Program is to develop sufficient knowledge about the Sun-Earth Connection as a System that useful predictions can be made on Space Weather and Global Change.*

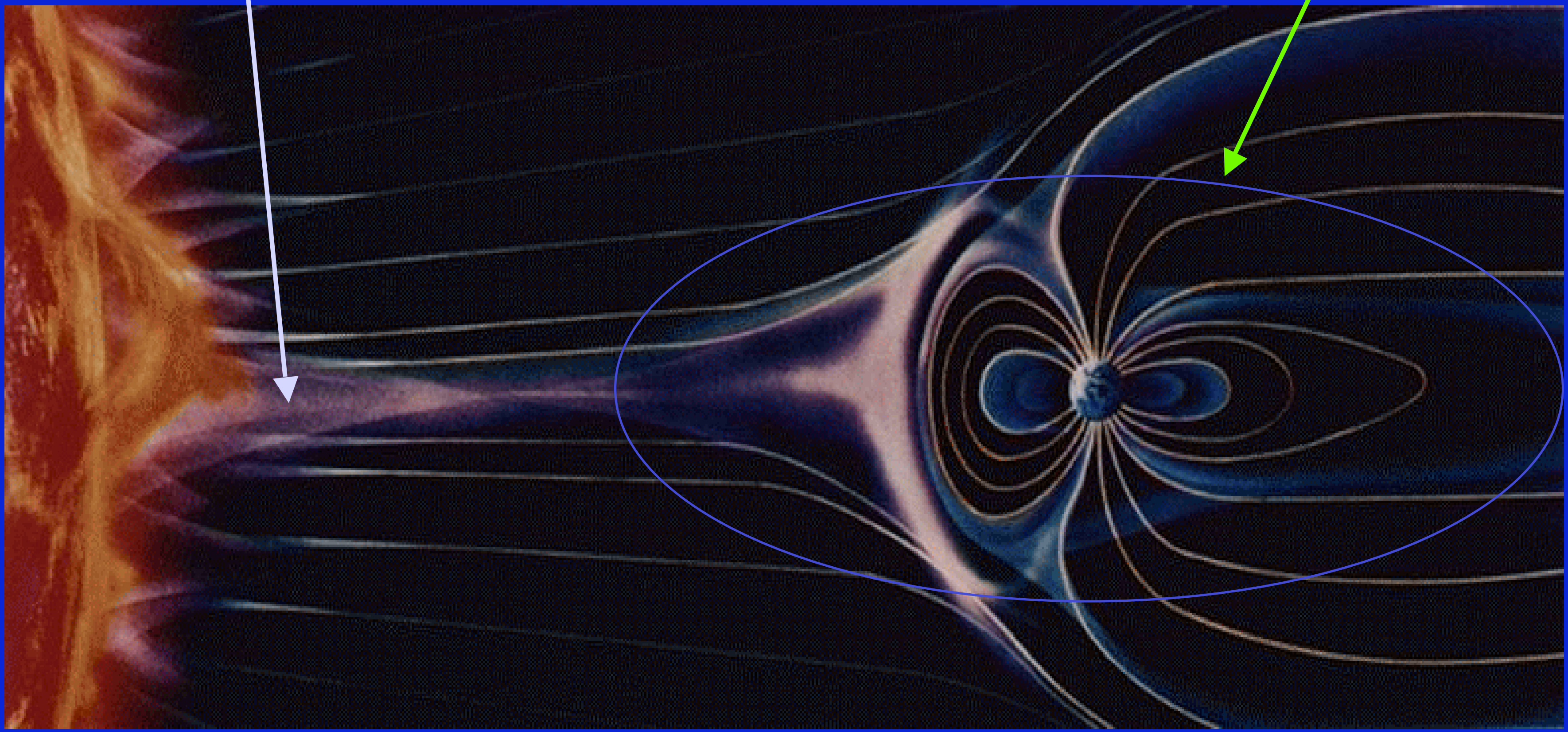
The Role of SEC in the Nation Space Weather Program



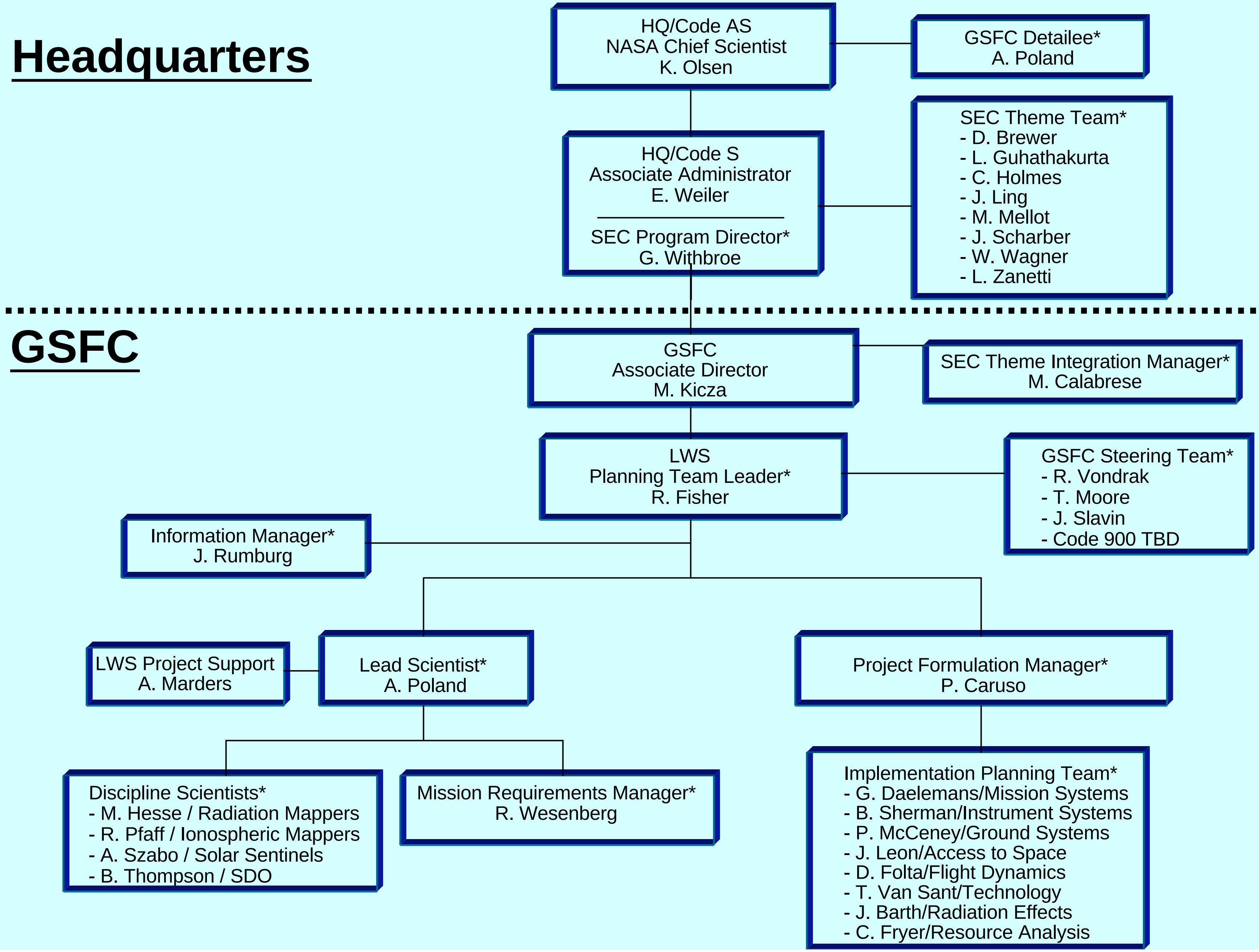
The Sun Earth Connection

Electromagnetic radiation and electrically-charged particles stream outward from the sun (the solar wind), envelop the earth, and interact with the earth's magnetic field and terrestrial atmosphere creating an adverse environment.

Solar Activity → **Near-Earth Effects**



Living With a Star: *Contacts* and Place in Organization*



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Understanding the Space Weather User Community

- SDO's purpose is to do *Focused Scientific Research*
- SDO's purpose is not just to collect parameters that are currently "useful" for groups generating predictions
- The SDO mission is a part of a systems approach to Understanding the Sun-Earth environment

LWS Approach - 1

- Fly a series of Scientific Spacecraft to uncover the fundamental physical processes in the domains of the Sun, Interplanetary Medium, and the Earth’s Magnetosphere and Upper Atmosphere.
- Develop data analysis, models, and theoretical tools to connect the process in the different domains.

LWS Approach -2

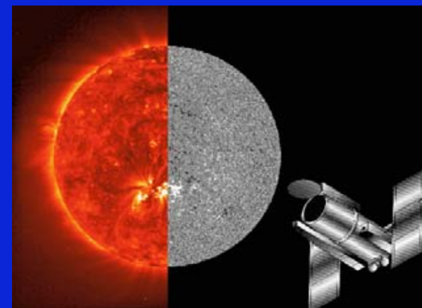
- Collect data over at least a complete solar cycle.
- Fly an evolving series of satellites to refine the that take coordinated sets of measurements.
- Leverage the Explorer and Solar Terrestrial Probe programs, EOS, International Spacecraft, and ground systems.

LWS Approach -3

- Develop tools that allow wide access to the data sets.
- Continuously work with “User” agencies to develop priorities for predictions.
- Develop data sets that from the initial stages are agreed to have predictive utility.

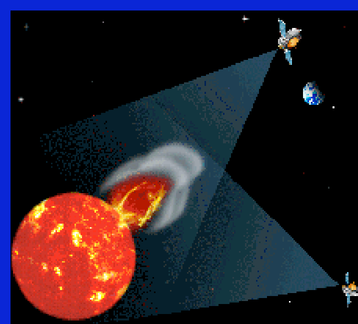
Current SEC Missions

Solar-B

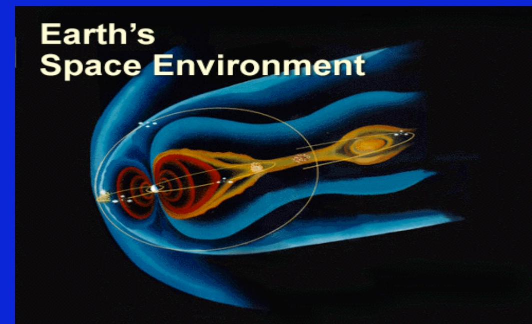


- Probing solar magnetic variability
- How is magnetic energy stored and explosively released to cause flares and coronal mass ejections?
- How are solar magnetic fields created and destroyed?

STEREO



- Stereo imaging of Sun; coronal mass ejections from birth to Earth impact.
- What determines the geo-effectiveness of solar mass ejections?
- What is their role in generating solar energetic particles?
- Research tool and prototype space weather & early warning system for solar energetic particles



Magnetospheric Multiscale

- Investigate magnetospheric response to coronal mass ejections.
- Investigate magnetic reconnection, plasma turbulence, and energetic particle acceleration with 5 formation-flying smallsats.

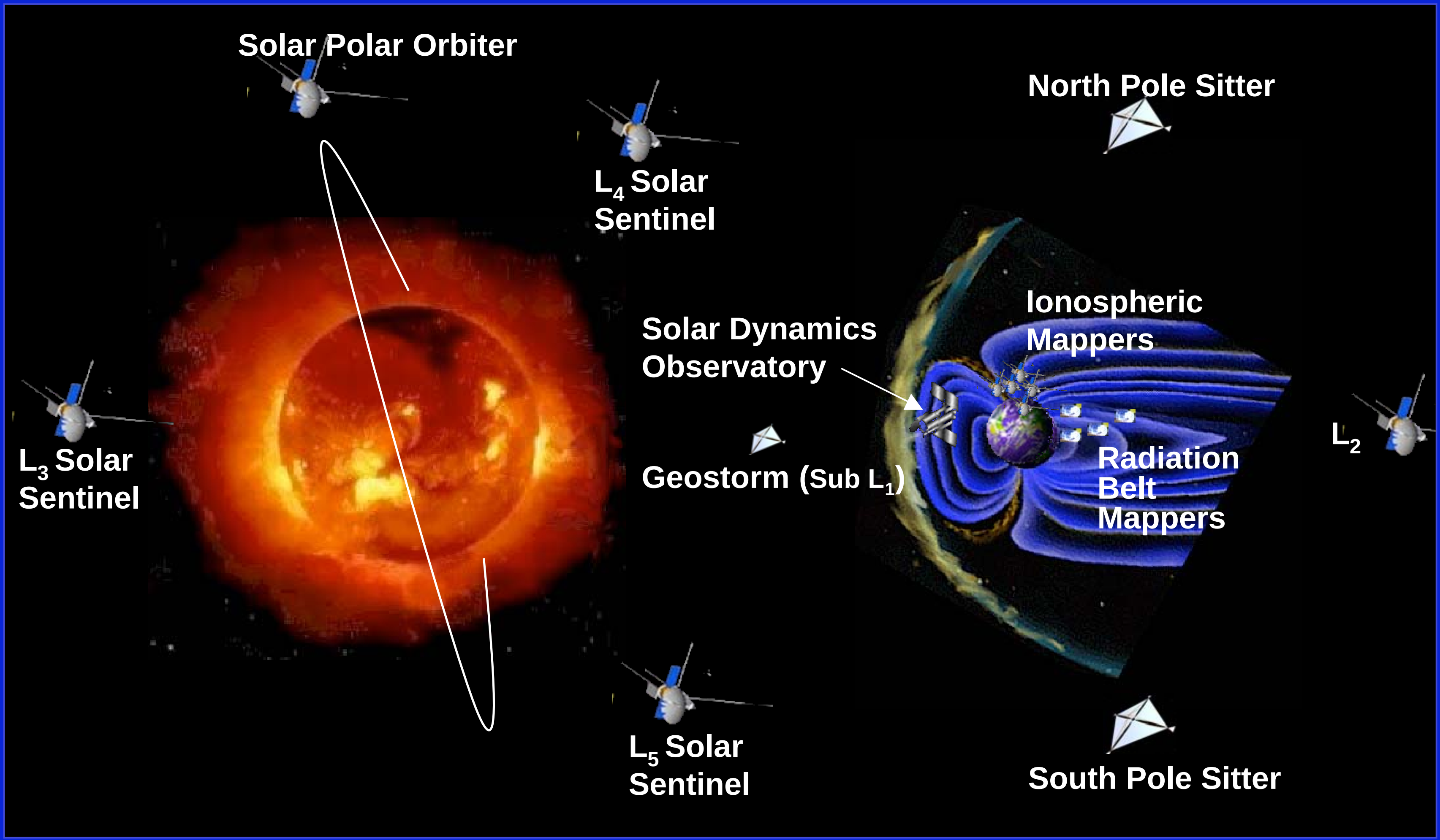
Geospace Electrodynamics

- Probe electromagnetic coupling between the Sun and terrestrial upper atmosphere with 5 formation-flying smallsats.

Magnetospheric Constellation

- Probe dynamics of geomagnetic tail with network of 20-100 nanosats.
- Test MHD storm theories.

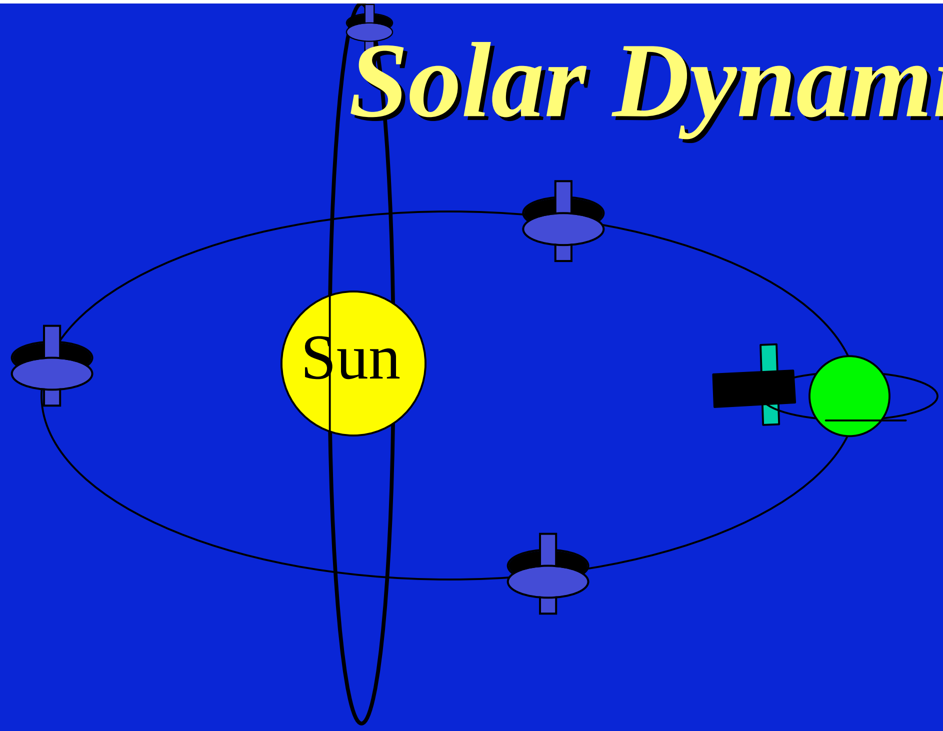
What Capabilities Need to be Added



Distributed network of spacecraft providing continuous observations of Sun-Earth system.

- *Solar Dynamics Network* observing Sun & tracking disturbances from Sun to Earth.
- *Geospace Dynamics Network* with constellations of smallsats in key regions of geospace.

Solar Dynamics Network



Solar Dynamics Observatory
(Next Generation SOHO)

- *Exploit geosynchronous* (GEO) orbit for high telemetry rate for studying dynamics.
- Observe:
  - Dynamics of solar interior, surface, and corona.
  - Flares & coronal mass ejections and their source regions from subsurface roots to corona.
- *Powerful tool for understanding solar dynamics, solar dynamo.*

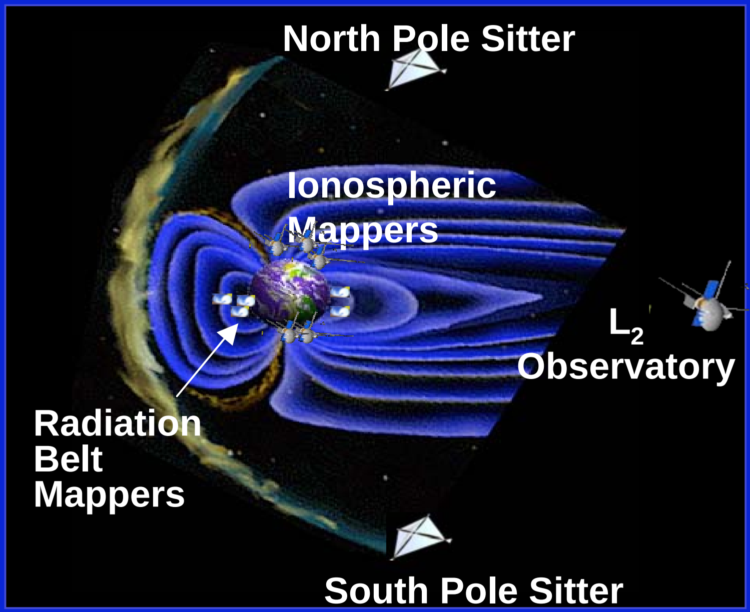
Solar Sentinels

- Spacecraft at L4 & L5 positions, far side of Sun *to provide global solar viewing and stereo imaging.* [Individual regions on the Sun are out of view from Earth for 2 weeks out of 4.]
- Observe:
  - *Development of solar "weather" over full sun (including backside).*
  - Solar flares and coronal mass ejections
  - Disturbances during transit from Sun to Earth

Solar Polar Observatory

- *Observe from above:*
  - Solar polar interior and exterior.
  - Propagation of solar wind disturbances in eclipitic plane.
- Stereo viewing with SDP and/or SS.
- Spacecraft injected into polar orbit by solar sail propulsion; one year orbit; *maintains 60 - 90^o angle to Earth-Sun line.*

Geospace Dynamics Network



Radiation Belt Mappers

- Determine dynamics and evolution of radiation belts.
- Quantify evolution of energetic particle populations.
- Satellite network from LEO to beyond geosynch orbits using NASA and partner spacecraft.

Ionospheric Mappers

- Determine global variations of ionosphere.
- Imaging aurora, inner magnetosphere, earthward moving plasma during storms.
- Satellite array in LEO for sampling regions multiple times/day.
- Smallsat observatory at L2 imaging nightside.

Pole Sitters

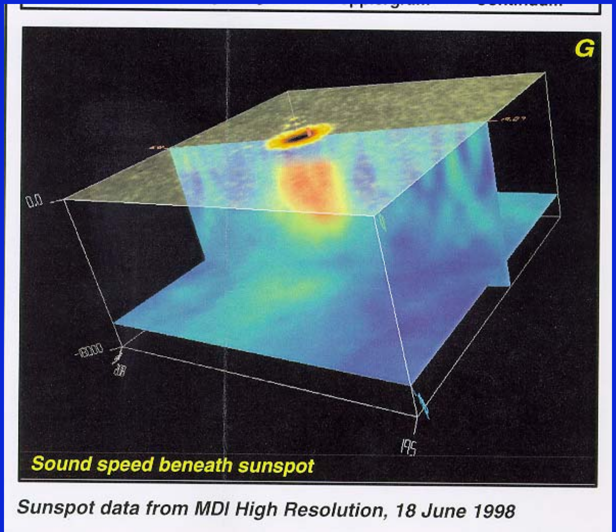
- Imagers above terrestrial poles (pole sitters - requires solar sails to maintain orbit).
- Sustained imaging of polar regions, plasmasphere, aurora, geocorona and inner geospace.

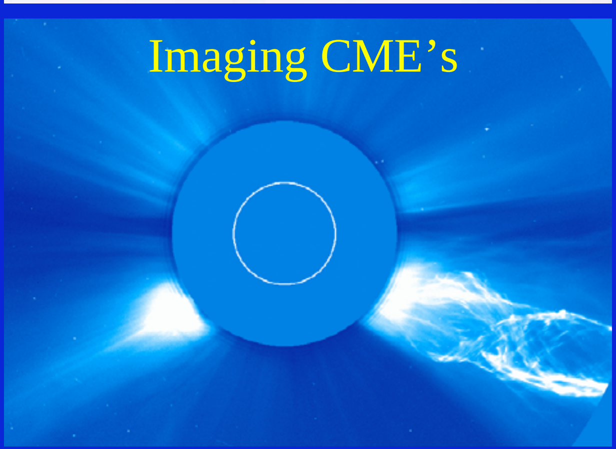
Solar Dynamics Observatory - Next Generation SOHO

Imaging Magnetic Structures

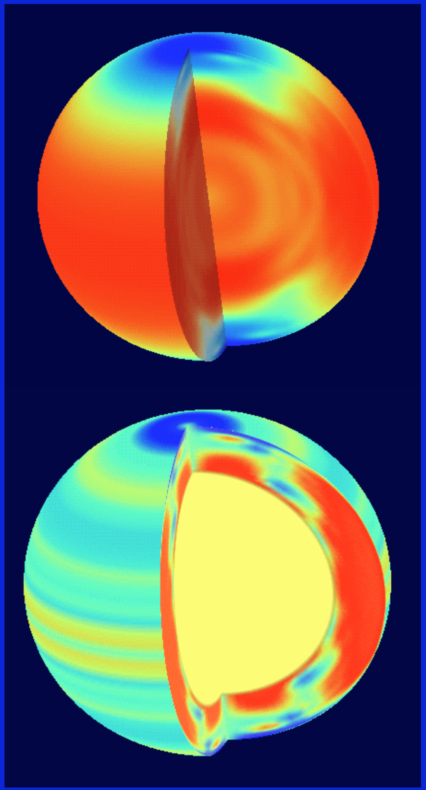
(rapid time sequences -- "movies")

Imaging Subsurface Structures





Imaging Solar Interior



Red: Faster Rotation

Blue: Slower Rotation

Solar Dynamics Observatory - Top Level Goals

- To understand basic physical processes in the Sun and its extended outer atmosphere
- To be a part of the Living with a Star (LWS) program which aims to understand the coupled physics of the Sun, the interplanetary medium, the Earth's magnetosphere and atmosphere, and Global Change
- To develop predictors of various solar process to aid in the forecasting of events of potential danger or damage to workers in space, scientific and commercial spacecraft, high-altitude aircraft, and the Earth's communications and power-distribution systems.

Solar Dynamics Observatory - Scientific Goals

- To understand how magnetic fields appear, distribute, and disappear from their origin in the solar interior to 18 solar radii from the solar surface.
- To understand the magnetic topologies that give rise to rapid high energy release processes that occur on scales from a thousand to many hundreds of thousand kilometers.

Major Science Questions for SDO - 1

- Why are there sunspots and solar active regions?
- How do magnetic regions emerge, evolve and decay?
- How do the active-region fields interact with the small-scale fields?
- Do local dynamo processes occur?
- How does the large amount of magnetic energy that is created at small scales dissipate?
- How are small and large-scale coronal magnetic field reorganizations related?

Major Science Questions for SDO - 2

- What are the surface and subsurface magnetic configurations that lead to CME's and flares?
- How important are cascading processes of flux emergence to large-scale flux evolution and expulsion?
- To what extent are CME's and flares predictable?
- How do active regions and the magnetic carpet affect solar convection and irradiance?
- How are the dynamics of the interior and the quiet and active solar corona linked?

SDO Baseline

- The current SDO is an evolution of the SONAR program in the NASA Roadmap
- SDO is described in detail and highly rated in the Astronomy and Astrophysics Decadal Survey Report
- SDO is summarized in the SDO Mission Draft Document that was distributed by e-mail

SDO Approach

- Observe the solar interior from the core to the surface.
- Image the top half (in pressure and density)of the convection zone.
- Measure the vector magnetic field at the solar surface.
- Image the upper atmosphere and corona in temperature regimes from 4 10^3 to 9 10^6 K.
- Measure the solar luminosity.

SDO Data Products

- Maps of the Interior flows, temperatures, and magnetic fields,
- Maps of surface Vector Magnetic field and velocity pattern,
- High Resolution stigmatic spectra,
- Images of the Corona at temperatures that span 40,000 K to 9,000,000 K,
- Images of the electron density, white light corona, from 0.05 to 30 Solar Radii,
- Irradiance Maps of the surface.

SDO Method

- Observe continuously for many months at a time
- Make all visible and UV images simultaneously on a 10 second cadence
- Make vector magnetograms on a 5 minute cadence
- Make surface velocity measurements on a 45 second cadence
- Make a well defined and unchanging set of measurements

SDO Operations

- Have a single data operations center with:
  - Experiment Control
  - Instrument and Spacecraft engineering
  - Data reception and level zero and one processing
- Maintain several data archives in mirror sites
- Make all data available in near real time
- There is no proprietary data

SDO Science Approach - Challenge Teams

- Define a set of Science Challenges with Specific Goals
- Compete these Challenges via NRA's and AO's as appropriate
- Hold Yearly Challenge Workshops that are open to both the scientific and user community
- Have the Science Challenges Reviewed on a 2 Year Cycle by a SDO Science Steering Committee that is composed of members of the LWS and Space Weather communities

What is a Challenge

- A Focused Scientific Research Problem that requires a range of expertise.
- A problem that has important consequences for understanding and has important effects on the Sun-Earth system.
- A problem that will require 3 or more years of sustained effort.

Who Should Support Challenge Teams

- SEC as the core of the focused research for LWS
- Partner agencies with particular interests
- Multiple Partner agencies, NASA, ESA, and ISAS
  - This is an opportunity to form teams via the web that combine operational needs and scientific research.
  - This is an opportunity to leverage information, computer technologies, and models across agency boundaries.

SDO Science Approach - Individual Grants

- Yearly NRA's for:
  - innovative scientific research using of SDO data will be issued
  - new instruments for follow-on missions will be issued
  - new technology for both instrumentation and data usage will be issued

SDO Science Approach - The Distributed SEC Laboratory

- All LWS and as much other data as possible accessible via a single catalog and data base.
- All numerical simulations and models supported by LWS also available via the catalog.
- Development centers of 3D visualization techniques for connecting different data sets.
- Create focused visualization centers associated with Challenge teams.

The Relation of SDO to Other Science Assets

- The Stereo Mission will provide data on the 3D structure of the corona.
- The Solar B mission will provide very high resolution vector magnetic field data and spectral imaging.
- The ESA-F Mission will join SDO as part of the Next Generation SOHO.

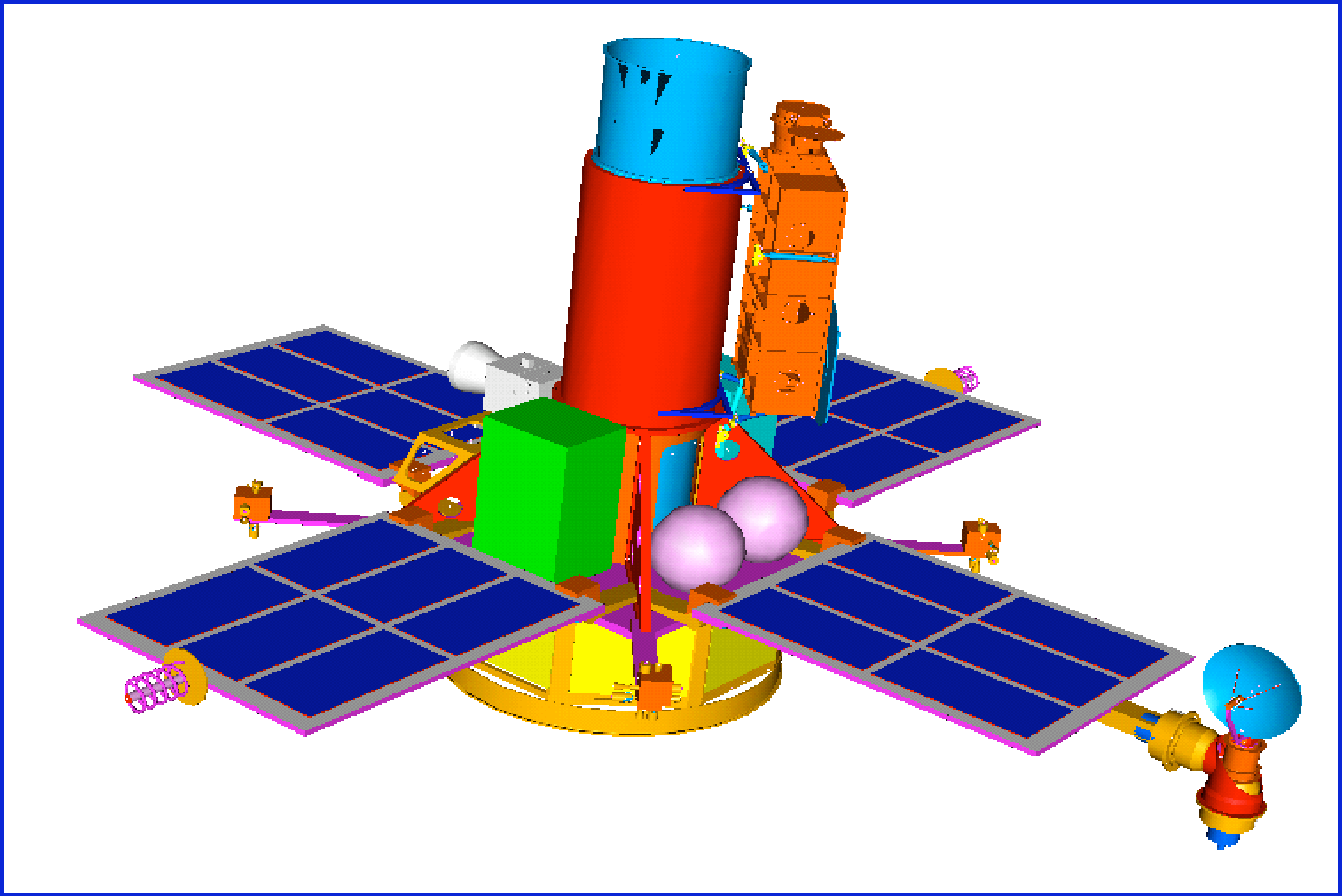
SDO Evolution

- SDO is just the first LWS mission to understand the cyclic variation of the Sun.
- Based on data from SDO and other missions SDO Versions 2 and beyond will be developed.
- The LWS new instrumentation and technology grants and the results of the LWS program will determine the nature of the follow-on missions.
- There should be a three year development cycle for the spacecraft and a half solar cycle for the launch of the missions (~6 years).

SDO Instrument Complement

- Helioseismic and Magnetic-field Imager (HMI)
- Atmospheric Imager Assembly (AIA)
- Coronal Imager Assembly (CIA)
- Irradiance Imager
- Spectroscopic Imager

SONAR Concept



Helioseismic and Magnetic-field Imager (HMI)

- Modified version of Michelson Doppler Imager on SOHO
- Deletes Dual Image Scale mode of MDI
- Contains separate filter systems for Helioseismology and Magnetic fields
- Contains 2 4096 x 4096 CCD’s (one Doppler-one Magnetic)
- FOV 36 x 36 arc minutes
- Pixels size 0.527 arc seconds

HMI properties

- Aperture 12.5 cm
- Optics Package wt 24 kg
- Data Rates
  - One 4096 x 4096 by 8 bit Doppler data product every 5 seconds ~2.7 10^7 bits/sec
  - One 4098 x 4096 by 6 bit Magnetic Data Product every 20 seconds ~ 6.7 10^6 bits/sec
- Data Products
  - One Helioseismology data set every 45 seconds
  - One Vector Magnetogram every 5 minutes

Atmospheric Imager Assembly (AIA)

- Six ~half scale versions of the TRACE telescope mounted as a cluster.
- Each of the EUV telescopes is dedicated to a single wavelength band.
- A visible-UV telescope contains a filter wheel with 6 wavelength channels.
- All of the telescopes can expose simultaneously.

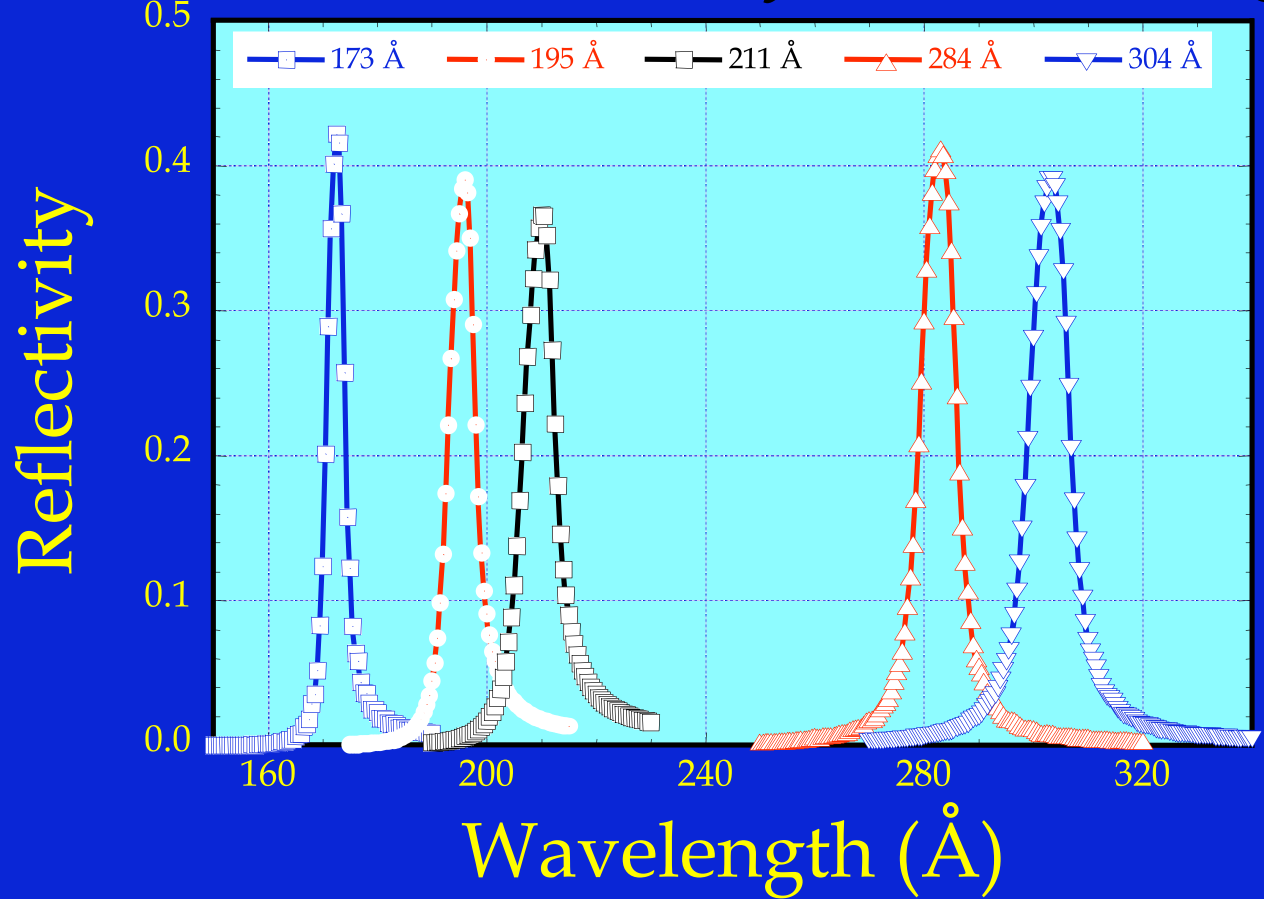
AIA Properties

- Telescope Aperture 12 -15 cm
- Telescope Length 1.3 meters
- FOV 36 x 36 arc minutes
- Pixel Size 0.527 arc seconds
- Each telescope has a 4096 x 4096 CCD
- Data Rate is one image every 10 seconds in 10 wavelengths
  - Six Simultaneous
  - 6.76 10^7 bits/second

AIA Candidate EUV Wavelengths

- 304 He II 100,000 K
- 171 Fe IX 800,000 K
- 195 Fe XII 1,000,000 K
- 211 Fe XIV 1,600,000 K
- 284 Fe XV 2,000,000 K
- 133 Fe XX 9,000,000 K

Multilayer Reflectivities as a Function of Wavelength



Troy W. Barbee, Jr., Lawrence Livermore National Laboratory Jan., 18, 2000

EUV Multilayers Structural Parameters and Performance

λ (Å)	Materials	Period (Å)	N	gamma	δλ (Å)	R (%)
171/175	ZrSi2/Si	89	100	0.38	3.7/2.8	42.2
195	ZrSi2/Si	102	100	0.35	5.5/4.0	39
211	ZrSi2/Si	110	100	0.32	6.9/4.8	36.6
284	Si/Mg2Si	147.5	60	0.48	6.8/5.6	41.2
304	Si/Mg2Si	159	70	0.42	8.4/6.1	39

Troy W. Barbee, Jr., Lawrence Livermore National Laboratory Jan., 18, 2000

AIA UV Wavelengths

- 1900 Continuum
- 1700 Continuum
- 1600 Continuum
- 1550 Narrow Band C IV
- 1216 Narrow Band H I
- Broadband Visible

Coronal Imager Assembly (CIA)

- Two Coronagraphs
- Inner Coronagraph Overlaps AIA FOV
- Outer Coronagraph Overlaps Inner
- Both Make Polarization Measurements

Inner CIA Properties

- Telescope Aperture TBD cm
- Telescope Length TBD meters
- FOV 33.6 to 72 arc minutes
- Pixel Size 1.054 arc seconds
- Telescope has a 4096 x 4096 CCD
- Data Rate is one image every 10 seconds in 4 Polarization States
  - $2.68\ 10^{7}$ bits/second

Outer CIA Properties

- Telescope Aperture TBD cm
- Telescope Length TBD meters
- FOV 2 to 18 Solar Radii
- Pixel Size 8.422 arc seconds
- Telescope has a 4096 x 4096 CCD
- Data Rate is one image every 10 seconds in 4 Polarization States
  - 2.68 10^7 bits/second

Irradiance Imager

- TBD

CCD Detectors Overall

- All Imagers use the same CCD Mask Set
  - Visible Light Detectors are front illuminated
  - UV and EUV Detectors are thinned back illuminated
- Readout Time is 2 seconds
- Exposure Time Controlled by Shutter
  - Exposure Range - 0.05 to 10 seconds

CCD Detectors Requirements

- 4096 x 4096 CCD - 9 micron square Pixels
- Full Well - 100,000 electrons
- Readout Noise - 50 electrons
- Operating Temperature - ~ 200 K
- Readout Rate is 2 MegaPixels/second
  - Implies 8 amplifier chains per CCD

CCD Radiation

- EEV CCD Detectors with the same design architecture as the SDO devices have been tested for the geosynchronous orbital conditions
- 3 mm equivalent of Aluminum is sufficient shielding
- Because of the optical design all SDO focal planes can be completely shielded